Sidelobe Suppression in OFDM Systems using Suitable Map in Constellation Expansion Method

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ABSTRACT:
Orthogonal frequency division multiplexing (OFDM) suffers from high out-of-band (OOB) radiation. Constellation expansion (CE) is one of the methods for reduction of OFDM sidelobes that has a good performance. In CE, no side information needs to be transmitted and it doesn't involve complex optimization problem but, it has an increment in the bit error rate (BER) parameter. In this method, the symbols map to the high order constellation that, the CE performance depends on this map of symbols. The selected map directly affects on sidelobes reduction. In this letter, we compare the different maps in CE method and propose a suitable map that has the best sidelobes reduction. Simulation results show that the proposed map reduces the OFDM sidelobes significantly.

KEYWORDS: OFDM; sidelobe; constellation expansion; map.

1. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation that has been a prime candidate for many recent communication systems. OFDM has high spectral efficiency and is robust against channel imperfections [1]. Recently, high demands for scarce spectrum resources forced us to use overly systems such as cognitive radio (CR). In CR systems, the white space of licensed frequency band utilizes for secondary users (SUs). For the OFDM system does not require continuous frequency spectrum, it is one of the best candidates for the CR system [1], ;2]. On the other hand, OFDM suffers from high sidelobes power level that radiates to out-of-Band (OBB) and interferes with licensed users (LUs). Therefore, the sidelobes of SUs signals need to be suppressed sufficiently in order to enable coexistence between SUs and LUs [3].

The first two methods for sidelobes suppression include the windowing of transmitted signal in time domain, and insertion of a frequency guard band [3]. But, the first method causes that the transmitted signal expands in time domain and latter method wastes the scarce bandwidth and thus, both methods reduce system throughput moreover, both of them have not enough reduction in OOB radiations. The other methods include: Insertion of cancellation carriers (CCs) [4] that, it has complex optimization problem to determine the CCs index and a number of subcarriers sacrifice in this method. Subcarrier weighting (SW) [5] that, it involves complex computation proportional with the number of subcarriers and degradation in BER performance. Constellation expansion (CE) [6, 7] that, in this method the symbol mapped into a higher constellation but, it has to tradeoff in the increase of the number of iterations and the sidelobes reduction because it uses iterative algorithm. The other sidelobes reduction methods exist such as multiple choice sequences (MCS) [8], carrier by carrier partial response signaling [9], adaptive symbol transition (AST) [10], constellation adjustment (CA) [11] and combined methods [7], [12], [13]. But every of them, inside of their advantages have shortages in degradation of system performance, complexity of computation and level of the sidelobes reduction.

In this letter, the different maps illustrate for expansion the symbols in CE method and their effects compare together in sidelobes reduction and BER increment. Finally, a suitable map introduces that has the best sidelobes reduction.

The paper is organized as follows: In Section II, the system model with using CE block is described. In Section III, the CE method is described. In Section IV, the suitable map is introduced. In Section V, the simulation results of the maps are illustrated and finally, in Section VI conclusions are drawn.

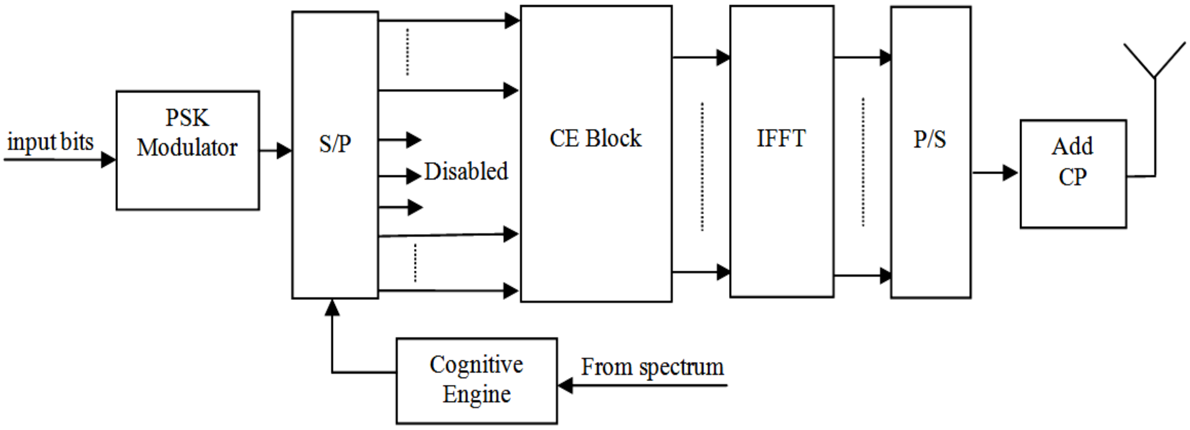

Fig. 1. Block diagram of transmitter for OFDM based CR with using CE method

2. SYSTEM MODEL

Figure 1 illustrates the block diagram of CR transmitter that used OFDM and CE method for reduction of the sidelobes. At the transmitter of the OFDM system, the input bits are first modulated to symbols and then, split into N parallel data stream in serial-to-parallel (S/P) converter, where N is the number of OFDM subcarriers. Cognitive engine block senses the spectrum for detection of the LUs and then, disables the frequency index related to LUs in S/P converter. The remaining active subcarriers are fed into the CE block that in this unit, the symbols map to extended constellation and then, the sequence of N symbols with a low OOB radiation selects. The inverse fast fourier transform (IFFT) applies to the selected sequence. Finally, the cyclic prefix (CP) is added to signal followed by the parallel-to-serial (P/S) converter. The length of the CP should be greater than the channel delay in order to combat the inter-symbol interference (ISI).

At the receiver the inverse of operations that used in transmitter perform. At the first, the CP of signal discard and after S/P conversion, the fast fourier transform (FFT) applies. Then, with using P/S converter the symbol sequence is ready for demodulation. With assumption of that the extended constellation is known for receiver, no side information needs to be transmitted.

The OFDM signal spectrum consists of N Sinc functions that, every Sinc function carries one data symbol. Therefore, the sidelobes power level is given by [8]:

$$S(x) = \sum_{n=1}^{N} d_n \frac{\sin(\pi(x - x_n))}{\pi(x - x_n)} \quad (1)$$

Where S(x) is the OFDM signal spectrum, d_n is data symbol, N is the number of subcarriers and x is the normalized frequency which is given by:

$$x = (f - f_0)T_0 \quad (2)$$

Where f_0 is the center frequency, T_0 is the OFDM symbol duration, and x_n represents the normalized frequency of the n^{th} subcarrier.

3. CONSTELLATION EXPANSION METHOD

The constellation expansion is a new method in reduction of OFDM sidelobes. In fact, this method uses an idea that, the different symbol sequences have different sidelobes power. CE method consists of two parts. In the first, the symbols map to the extended constellation with use of a proper map and then with use of iterative algorithm, the best sequence of symbols which has minimum sidelobes power selects for transmission.

In constellation expansion that proposed in reference [6], the constellation is extended for new sequences production of the symbols. Assume that, we used a MPSK modulation scheme that every K bits are modulated into one symbol therefore, the constellation consists of 2^K points. In CE, every point of constellation is mapped to two points in an extended constellation and we have two choices for every symbol. Therefore, the extended constellation consists of 2^{K+1} points. With assumption that, the receiver is aware of the relationship between the main constellation and the extended constellation; no side information needs to be transmitted.

We consider an OFDM system with N subcarriers and we have two choices in extended constellation for every symbol therefore, the 2^K new sequences produce with different sidelobes power and the best sequence can be chosen. In reference [6], an iterative algorithm is used and by computation of the sequences sidelobes power, the sequence that has minimum sidelobes power chooses for transition. By considering the high number of iterations, this approach leads to high computation for system. So, there is a tradeoff in the increase of the number of iterations and the sidelobes reduction. In [6], the iteration number is chosen 64.

CE method has a good performance in sidelobes reduction but it increases the BER parameter because in extended constellation, the symbol space is half of the original symbol space.

4. SUITABLE MAP IN CE METOD

The CE method consists of two parts that the first part depends on the selected map for symbols. This map affects on the reduction of sidelobes and increment of BER directly. In CE method, we have two points in extended constellation for every symbol that, the selected map determines the position of these two points. If the positions of these two points are in same quadrant, the degree of freedom decreases for production of the symbols sequence and if these two points have further difference in real or imaginary part, the degree of freedom increases and therefore, we obtain further sidelobes reduction. In following, we compare the different maps and propose a suitable map for CE method. In these maps, the original constellation is QPSK and the extended constellation is 8PSK.

4.1. Map with same sign in real and imaginary part

In this map, the real and imaginary part of the two points in extended constellation have same sign therefore; the degree of freedom for this map is in lowest level and the OFDM sidelobes reduction decreases and is lower than the other maps. Two points are side of together in extended constellation and therefore, this map has minimum BER increment. In figure 2, this map is illustrated.

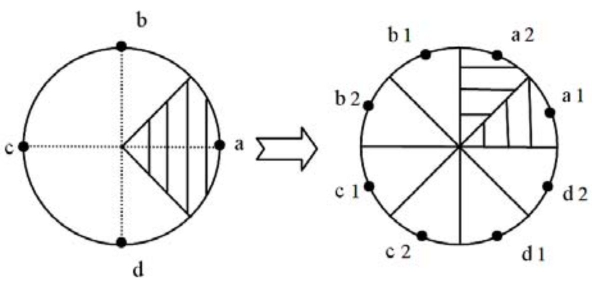

Fig. 2. The constellation expansion from QPSK to 8PSK with the map with same sign in real and imaginary part

4.2. Map with same sign in real or imaginary part

In this map, the two points in extended constellation have same sign just in one of the real or imaginary part and has different sign in other part. Therefore, this map has the degree of freedom more than first map and obtains better sidelobes reduction. In this map, the two points of the extended constellation are in two quadrants side of together so; the BER is more than of the first map. In figure 3, this map is shown.

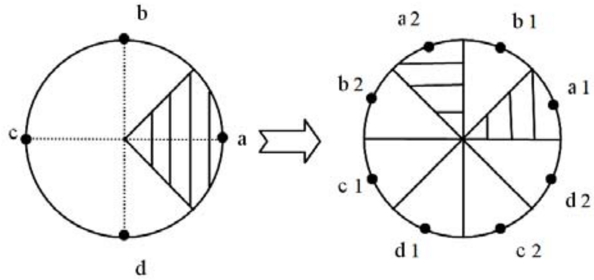

Fig. 3. The constellation expansion from QPSK to 8PSK with the map with same sign in real or imaginary part

4.3. Map with different sign in real and imaginary part

In this map, both of the real and imaginary parts of the two points in extended constellation have different sign. This map has maximum degree of freedom and therefore, obtains the best reduction in OFDM sidelobes. The BER increment of this map is same the second map. In figure 4, this map is illustrated.

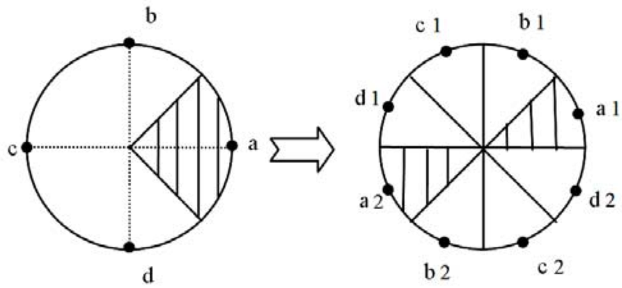

Fig. 4. The constellation expansion from QPSK to 8PSK with the map with different sign in real and imaginary part

4.4. Map on the real or imaginary axis

In this map, one of the two points in extended constellation maps on real or imaginary axis. In this map, the degree of freedom is suitable but it is lower than third map. Therefore, the sidelobes reduction of this map is lower than third map but the BER is same the second and third maps. In figure 5, this map is shown.

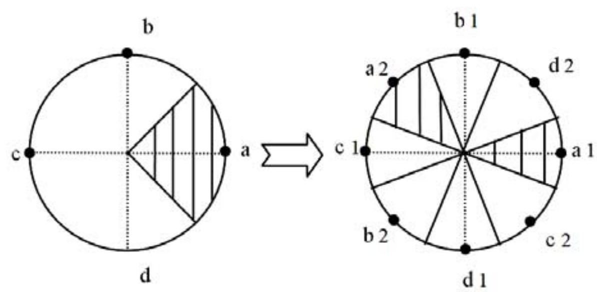

Fig. 5. The constellation expansion from QPSK to 8PSK with the map on the real or imaginary axis

5. SIMULATION RESULTS

In this section, an OFDM system with N=128 subcarriers is considered for comparison between the sidelobes reduction of the different maps in CE method. Moreover, an OFDM system with N=16 subcarriers is considered for comparison between the BER of the different maps. The QPSK modulation is used for OFDM system and its extended constellation is 8PSK. All of the results shown are averaged over 5000 OFDM symbols and same as the reference [6], iterative algorithm with 64 repetitions is used for CE method.

In Figure 6, the power spectrum density (PSD) of the OFDM signals with N=128 subcarriers are illustrated for the original OFDM signals and CE method with first, second, third and fourth maps. Simulation result shows that first map has minimum sidelobes reduction with 4 dB and then, second and fourth maps have 6.5 dB and 10.5 dB reduction in OFDM sidelobes. Third map has the best performance in sidelobes reduction with 15 dB.

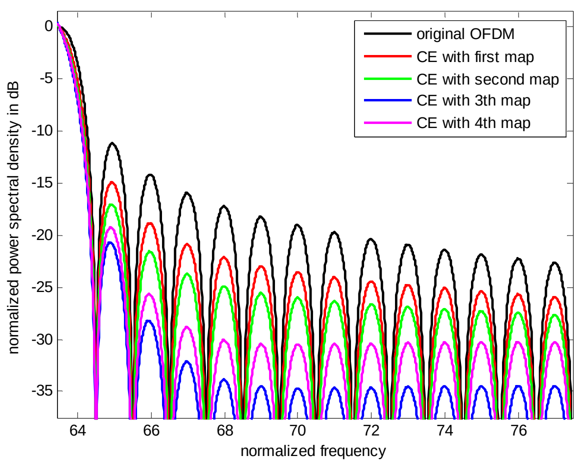

Fig. 6. Power spectrum of original OFDM signal and CE method with first, second, 3th and 4th maps

For calculation the system BER, OFDM signals pass from AWGN channel with different signal to noise ratio. In figure 7, the BER of the OFDM signals with N=16 subcarriers are shown for the original OFDM signals and CE method with first, second, third and fourth maps. Same as which we expect, first map has minimum BER and other map have same BER and their BER are more than first map.

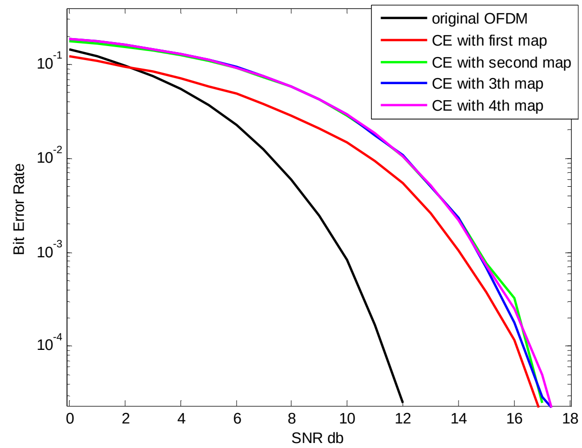

Fig. 7. BER of original OFDM signal, CE method with first, second, 3th and 4th maps

6. CONCLUSION

CE is a new and effective method for OFDM sidelobes reduction. This method depends on the utilized map and the map directly affects on sidelobes reduction. In this paper, we compare different map in CE method and propose a suitable map that hase the best performance. This map significantly decreases OFDM sildelobes. The different maps and their performance compared together in simulation and simulation results showed that third map has the best performance in sidelobes reduction with 15 dB.

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